TESTING THE INTERACTION OF STIMULUS REPETITION WITH SWITCH COSTS ACROSS AGE GROUPS

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SUMMARY

Task-switching studies are a popular measure of executive control, yet the influence of stimulus repetition in these studies is less well recognized. One theory from the literature states that stimuli associated with a certain response interfere with processing of those same stimuli in another task, contributing to task switching costs (Waszak, Hommel, & Allport, 2003). The current study varied stimulus repetition in younger and older adults and found that the previous task associated with a stimulus does influence overall performance but did not find the expected interaction of switch and repetition conditions. Results of this study extend our information about the role of stimulus repetition in task-switching studies as well as how this repetition relates to age differences in switch costs.

CHAPTER 1

INTRODUCTION

Our environment is demanding. Many cognitive processes are required in order to respond appropriately to the current demands imposed by our goals and of the environment. Additional control is necessary to manage these processes, especially in a dynamic world. Broadly, executive control can be defined functionally as the top-down, volitional management needed for a given situation. Executive processes have the ability to disable or disengage a strategy based on changes in the task environment (Logan, 1985) and include monitoring for errors, controlling ongoing responses, overcoming competition, and coordinating multiple tasks (Logan, 2003). Processes that demand executive control include verbal processing, short-term memory storage, and spatial visualization (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001). This broad collection of functions reflects the fact that the definition of executive control often depends on the task that is used to measure it. Not all executive control tasks measure the same thing. For instance, updating working memory and switching tasks have different types of measures and such abilities are separable, yet both are considered executive functions (Friedman, Miyake, Corley, Young, DeFries, & Hewitt, 2006).

In a dual task experiment, for example, multiple stimuli are presented in close temporal proximity and require discrete responses. Executive control is needed to schedule or manage multiple instances of stimulus processing and response preparation. The cognitive system must encode stimuli for both tasks, determine the order of response execution, respond to the primary task stimulus, and then respond to the secondary task's

stimulus. Coordinating these processes falls to the executive control mechanism to ensure that encoding and responses are appropriate for each task. In a task-switching study, on the other hand, only one task is presented at a time so there is no need to coordinate multiple responses, but the single task required on each trial changes from trial-to-trial (Rubinstein, Meyer & Evans, 2001). In task-switching, the system must distinguish between appropriate and inappropriate responses for relevant features of a stimulus on each trial based on the task instructions.

The execution of a correct response for a given task requires the engagement of executive control as well as encoding the stimulus for that task. Higher level cognitive control (top down) processes interact with the automatic, stimulus-driven (bottom-up) processes activated by properties of the encoded stimulus. For example, a letter string cue can automatically trigger reading. The fact that we can avoid overt word reading in favor of naming the color of a word (Stroop, 1935) reflects the fact that control processes can overcome these environmental cues. These control processes operate in the context of processing information from the environment.

Executive control is often related to the age of a participant (e.g. Wecker, Kramer, Hallam & Delis, 2005), but not all measures of executive control find age interactions between younger and older adults, especially after accounting for individual differences in overall speed (e.g. Reimers & Maylor, 2005). One critical question to understand this discrepancy is how the balance of top-down and bottom-up processes may change across the life span. Specifically, I examine the interaction of bottom up (stimulus based) and top down (volitional control) processes using the task-switching paradigm. The first section of this paper reviews some of the basic empirical results from studies of task switching. Second, I discuss findings that demonstrate significant top down control influences in task switching. Third, several lines of evidence demonstrate stimulus-driven

influences in task switching, I then specifically look at contributions of stimulus priming. Certain executive control processes such as response inhibition have been argued to be age sensitive (Troyer, Leach & Strauss, 2006), and thus the final section further examines evidence for age differences in switching ability. The experiment examines stimulus repetition effects in task-switching, followed by a discussion of how the results relate to one current theory of task switching. The aim of this experiment is to further parse the specific executive control processes involved in task-switching experiments by investigating the role of stimulus repetition in the time needed to respond to trials in a switching condition.

Task-Switching Paradigm

In task switching designs, participants perform one task per trial, but the relevant task changes from trial to trial (e.g. Allport, Styles, & Heish, 1994; Rogers & Monsell, 1995). For example, a subject sees letter/number combinations (e.g. G8) and must respond with either a left or right hand keypress. For each stimulus pair, the participant is asked to make a discrimination response either to the letter (vowel/consonant) or the number (greater or less than 5), often based on a cue designating the task to perform. For some trials participants engage in the same discrimination task as the trial just before (nonswitch trials), while in other trials participants perform a different task from prior trials (switch trials). Switch trials have longer response times (RTs) and higher error rates than nonswitch trials (e.g. Allport et al., 1994; Kramer, Hahn & Gopher, 1999; Rogers & Monsell, 1995; Ward, Roberts & Phillips, 2001). The difference in performance between switch and nonswitch trials within the same block is referred to as a local switch cost (Mayr, 2001).

Global switch costs are another measure of the difficulty of switching, specifically of the difficulty of performing a task in a switching context relative to a single task context (Koch, Prinz & Allport, 2005; Los, 1996). To calculate global switch costs, the mean RT of blocked single task trials is subtracted from nonswitch trials from the task-switching blocks. Trials in a single task block are nonswitch trials in a single task context and are compared to nonswitching trials in a task switching context.

Local switch costs may partly reflect the time needed for task set switching. A task set is a representation of instructions, joining stimuli and their associated responses for each task. In relation to the above example, suppose a subject must perform a discrimination response to the letter (G) of a stimulus (G5). The task set for letter discrimination is activated and the appropriate response is made. If the next trial requires a number discrimination, the letter discrimination task set must be disengaged and the number task set engaged. Cognitive control is responsible for the coordination of the task sets (Rogers & Monsell, 1995).

Both calculations of switch costs are influenced by specific stimuli and their associated responses as well as processes associated with reconfiguration of the task sets that organize them (Wylie & Allport, 2000). Specifically, stimulus-response bonds are formed once a response is made to a specific stimulus. The rampant stimulus repetition in many task-switching experiments means that the stimuli are paired multiple times with different responses over the course of the session. These response associations are retrieved when a stimulus is encoded. Switch costs reflect the accumulation of influences from stimulus encoding and the responses previously associated with stimuli. The next sections further discuss what leads to the switch costs measured in task switching studies. Switch costs show influences from both higher level control and stimulus encoding. Previous research has found evidence for both components in task switching conditions,

however the degree of each influence often depends on variables used in the experiment. Task cues, stimuli, and timing can all be manipulated in order to highlight either the control or stimulus influence.

Top Down Control Components of Task Switching

Cognitively demanding, volitional control could disengage one task and engage another. Such control is especially needed in the case of unpredictable switches that require adaptation on each switch trial (Ruthruff, Remington, & Johnston, 2001). Switch costs may reflect the time required for task sets to be reconfigured for the relevant task, since switch trials include the time for reconfiguration while nonswitch trials should not. Like switching train tracks, once reconfiguration is done, no additional time is needed on later trials. Nonswitch trials are faster than switch trials because the system is already configured for the stimulus-response associations of that trial's task (Rogers & Monsell, 1995). Reconfiguration of the active task representation leaves one task more activated than the other and this activation adds a bias to respond to an upcoming stimulus based on the currently activated representation of the task. In one of the earliest papers to measure local switch costs, Rogers and Monsell (1995) chose nonswitch trials as a baseline for measuring the control needed on switch trials. This assumes that reconfiguration is fully accomplished on switch trials, supported by their finding that runs of nonswitch trials within a task switching context do not continue to get faster.

A task cue may aid reconfiguration and help the subject prepare possible responses, one of which will be appropriate for the upcoming stimulus, based on the rules of the task set. A cue presentation gives part of the stimulus information in advance (Arrington & Logan, 2004) and allows task set reconfiguration to begin when the cue

appears. A decrease in RT on switch trials as the cue-to-stimulus interval (CSI) increases supports the role of top-down control to bias task representations in favor of the current task (Rogers & Monsell, 1995).

After task-sets have been used, they are suppressed on trials that switch to another task. Top-down control inhibits activation of a no longer relevant task set so that activation of the currently relevant task set will lead to a correct response. Inhibition then stays with the task-set that has been disengaged and makes it more difficult to return to that task (Mayr, Diedrichsen, Ivry, & Keele, 2006; Mayr & Keele, 2000). Mayr and Keele (2000) presented three and four tasks in a task switching situation. Target stimuli were presented along with distractors on the screen. RTs increased when returning to a task that had been abandoned 2 trials previously compared to a task that had not been so recently engaged. High level control is thus evident in changing back and forth among tasks. In an everyday environment, inhibiting a task that has already been completed might be adaptive. The task switching environment, however, can make this control detrimental. Task sets must be available, as they frequently move in and out of use while switching. Top down control works to select task sets in preparation for a trial, however, task sets are composed of specific stimuli associated with responses. Activation and inhibition of task sets takes places during ongoing stimulus processing that also biases performance. In the next section, I turn to the influence of the stimulus in task processing.

Bottom-up Components in Task Switching

The system may be biased to respond, in part, through automatic encoding of information from the environment, which includes the stimulus and the task cue. Task switching performance includes contributions from stimulus encoding (Hsieh & Liu, 2005), for which the reconfiguration hypothesis only partially explains the empirical findings. CSI manipulations are used to demonstrate the benefit of advance preparation to

help switch tasks, with a long CSI; reconfiguration of the task sets takes place before the stimulus appears and so switch costs are reduced. If internal reconfiguration of task representations accounts for the local switch cost, then allowing a sufficiently long CSI should eliminate switch costs whereas short CSIs require that both reconfiguration and stimulus processing take place after stimulus presentation. With long CSIs, time for internal reconfiguration occurs before stimulus onset, however, a significant residual switch cost remains even with a CSI of over a second (Rogers & Monsell, 1995; Sohn & Anderson, 2001). This CSI is longer than the local switch cost; thus, the reconfiguration that leads to local switch cost should have been completed within the preparation time. This suggests that the stimulus itself must be available for task switching to complete. Some information from stimulus processing is associated with switch costs.

To evaluate the role of task cues, Koch (2003) presented only a cue to switch tasks (not a specific cue for the task itself) and found that in this case switch costs were especially impervious to increased CSI, highlighting the role of a task cue to act as part of the distinctive stimulus information rather than an abstract marker to change task-sets. A cue that is not uniquely associated with any task does not seem to function as a part of the stimulus that could begin biasing the system to respond. A unique cue that identifies the task is associated with the stimulus with which it appears and the response for that trial. The cue then is a means to prepare the system to respond in a certain way to a particular stimulus. In Koch's study, the cue to switch that was not uniquely associated with any particular stimulus did not bias the response as much whereas presenting a cue for the actual task eliminates some switch costs (as in Rogers & Monsell, 1995).

Arrington and Logan (2004) have shown that a distinct cost appears when task cues are switched separately from the task that needs to be performed, in addition to the switch costs of changing the actual task. They presented participants with instructions for two tasks, each with two possible names as the task cue. Changing from one name to another of the same task constituted a cue-switch but not a task-switch. Changing cues while repeating the actual task leads to large cue-switch costs that account for much of the standard local switch cost. This suggests that task cues are a part of the environmental information that is presented to the subject, and therefore changing them is a change in the stimulus rather than an internal task-set. Thus, these findings point to strong influence from encoding the stimulus (information from the environment) in measures of switch costs.

Cue switching costs show that physical cues from the environment are a critical part of task switching costs but they do not replace task switching costs under all circumstances. Some (e.g. Logan & Bundesen, 2003) have claimed that the cue switching effects are evidence against an endogenous control component in switch costs. Monsell and Mizon (2006) found that task switching costs do reappear in modifications to the cue switching design including long CSIs and low switching probability. Rather than insisting that either top down control or stimulus encoding influences do not have impact, these studies together suggests that components of both influences may simply have boundary conditions under which they are most evident.

The type of stimuli and associations that form between stimuli and responses can also set boundaries on the conditions under which effects are found. Unique (univalent) stimulus sets do not lead to global or local switch costs (Allport, Styles & Hsieh, 1994;

Jersild, 1927; Spector & Biederman, 1976). A strict interpretation of reconfiguration theories would seem to predict that univalent stimuli would have similar influence from the stimulus-driven component of switch costs regardless of stimulus type, and that the time-consuming top down component should remain. The types of stimuli should not dictate the use of an internal process to reconfigure task sets. Activation of task sets that had to be engaged for a response to be produced would have to be controlled regardless of the stimuli. Yet, the tasks with which a stimulus is associated affect switch costs. Bottom up components in task switching include the automatic activation of task and stimulus response mappings associated with the stimulus. This paper focuses on the previous task history of stimuli in task switching contexts.

The history of a stimulus builds each time it is presented in the experimental session. Task-switching experiments typically repeat a small set of stimuli many times and use the same stimuli for each task. If on one trial a participant encounters the stimulus "G8" and has to respond based on the letter presented and then later encounters this stimulus again but has to respond based on the number, the participant has a stimulus-response association, but for the now irrelevant task. Using picture-word Stroop-style stimuli, Waszak, Hommel, and Allport (2003) found that having previously presented a stimulus in another task increased response time on switch trials even after more than 100 intervening trials between the first and second occurrences of the stimulus. Next, I focus specifically on this influence of stimulus history from repeated presentations in task switching.

Stimulus Priming in Task Switching

In an early account, Allport et al. (1994) explained local switch costs as a reflection of inertia from proactive interference that develops as the result of persistent activation from competing task representations and slows engagement of the relevant task set. For example, in switching between color and word reading in a Stroop task, activation of the color-naming task representation builds over color-naming trials. Switch trials that required participants to read the word suffered as the color-naming activation dissipated, typically by the following nonswitch word reading trial. The activated task representations may create a difficulty similar to having to suppress processing of information held in working memory once it is encountered again (Hester & Garavan, 2005). Lingering activation interferes with later activated task-sets and switch costs result due to the need to resolve the interference.

This notion of proactive interference has since been extended to include retrieval of responses previously associated with a stimulus (Wylie & Allport, 2000). Each experience of a stimulus creates a memory trace that is unavoidably retrieved on each subsequent presentation of the same stimulus (Logan, 1988). The endurance of memory traces leads to an explanation for long-term priming related to switch costs. Creating a memory trace of a stimulus-response bond aids similar future performance when the memory trace is retrieved but impairs performance if a different response is now required for a stimulus.

Priming Explanation for Bottom-Up Components

Memory traces activated by the stimulus explain why longer preparation times between a cue and stimulus do not eliminate switch costs. The presentation of a stimulus activates each memory trace associated with it, which brings about the conflict that

results in switch costs. Therefore, the inconsistency cannot be resolved until the stimulus object is presented. When the irrelevant attribute of a stimulus is associated with a currently incorrect response, the system must react to this conflict and cannot prepare for it in advance (Monsell, Sumner, & Waters, 2003).

Automatically retrieved memory associations also explain the lack of switch cost in independent stimulus sets such as those used by Jersild (1927). Distinct classes of stimuli are not bound to both tasks, thus with the onset of the stimulus, there is no inconsistency of information retrieved from memory and thus no switch cost. In Allport et al. (1994)'s task-switching study, the stimuli were originally unique for each task, color naming of Stroop word stimuli and numerosity naming for number stimuli (e.g. "5555555"). By allowing each stimulus to only be associated with a certain task for the first half of an experiment, Allport et al. replicated Jersild's results of no switch cost. However, in the second half of the study, the directions changed so that those same stimuli were associated with a complementary task, word reading the Stroop stimuli and naming the numerals of the number stimuli. Switch costs emerged only after stimuli were each associated with two tasks.

While useful much of the time in everyday life, these associations between stimuli and certain responses are not helpful in situations that re-pair stimuli with other responses, as in task-switching sessions. Not only are attended pieces of information included in the memory trace, but as in negative priming, actively ignored features may be as well (Neill, 1997). Therefore, if the task involves trying to ignore an aspect of a stimulus, such as reading the word when trying to name incongruent Stroop stimuli, this suppression aspect is bound into the memory trace. Waszak, Hommel, and Allport (2005) also tested competitor priming, that unhelpful memory traces are retrieved and impair

performance. Competitor priming occurred when the distractor of a stimulus had previously been a target. Such priming had a robust impediment on switch trials, especially when response set overlapped.

Further, the task cue is a component of the display and is bound into this memory trace (Hommel, 1998). Changing task cue (even though not actual task) retrieves a separate memory trace that competes for activation with the memory trace for the previous task cue. Including two possible cues for each task separates an exact cue and task repetition from just a task repetition (Brass & von Cramon, 2004; Logan & Bundesen, 2003). Therefore, cognitive reconfiguration of actual task representations may only be a small portion of what the switch costs measure once stimulus repetition effects are controlled. To control stimulus repetition effects includes taking into account the previous history of a stimulus and what role that previous history has for the participant who is responding to each stimulus. This role may be different for younger and older groups of adults.

Control and Aging

Comparisons between young and older adults further reveal the processes involved in task-switching. Executive control measures typically show individual differences in measures of working memory capacity (Engle, Kane, & Tuholski, 1999) and differences across age groups (Holtzer, Stern, & Rakitin, 2004). The pattern of executive control ability is seen as increasing throughout childhood, reaching a peak in adulthood, and declining in old age (Zelazo, Craik, & Booth, 2004). Older adults have been found to have variable ability to maintain executive control (West, Murphy, Armilio, Craik, & Stuss, 2002). However, the typical measure of local switch cost does

not usually convey this decline for older adults. West and Moore (2005) found no age interaction with local switch costs in a modified Stroop switching study. Overall, local switch costs in a variety of tasks are not significantly different for young and older age groups of adults (e.g. Hahn, Andersen, & Kramer, 2004; Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; Salthouse, Fristoe, McGuthry & Hambrick, 1998; Verhaeghen & Cerella, 2002). As a measure of the executive control required to disengage and to engage task representations, an important caveat must be inserted that aging does not affect this measure of executive control.

An increase in the CSI benefits older adults as it does young (Meiran, Gotler, Perlman, 2001). Top-down reconfiguration should take place in this interval before the stimulus appears. Older adults are able to use this reconfiguration time effectively to reduce switch costs. Either the CSIs are long enough for older adults to reconfigure more slowly and still complete the process or reconfiguration is not particularly age sensitive.

Consideration of the bottom-up processes that are accounted for by the memory trace explanation of switch costs broadens our understanding of what processes are not affected by aging. Creating memory traces is not an effortful executive control process and older adults may do this as well as younger adults (Fabre & Lemaire, 2005), especially when older adults do not have to divide their attention during the task (Jennings & Jacoby, 1993). However, once these associations between stimuli and responses have been made, the interference created by the different task associations grows with each exposure to a stimulus. Older adults may be more susceptible to this interference on both switch and nonswitch trials and have more trouble resolving it (Jonides, Marshuetz, Smith, Reuter-Lorenz, & Koeppe, 2000). However, because local switch costs are calculated as the difference between switch and nonswitch trials, the

local switch cost measure does not reflect the possible deficits of older adults in resolving interference of competing memory traces.

Recall that global switch costs (mixing costs) are measured as the difference between nonswitch trials in a switching context and the nonswitch trials of a single task context where there is no potential for switching. Using this measure and bivalent stimuli, older adults do show differentially more costs than younger adults (Kray & Lindenberger, 2000; Mayr, 2001). Nonswitch trials in a switching context have the same requirement as switch trials to overcome memory traces that are not relevant. Nonswitch trials in the single task condition do not have recently activated competing memory traces and may have less competitor priming to overcome. Older adults may not have a problem maintaining task representations or with holding the information necessary to correctly carry out a trial. Indeed, increasing the number of task representations that need to be held in working memory during the session does not increase global switch cost (Rubin & Meiran, 2005). Therefore, priming interference may be a better explanation of the age interaction in global switch costs than supposing that older adults' performance suffers solely due to the working memory demands of maintaining multiple task-sets.

The difference in stimulus-related conflict that appears between single task and task-switching blocks need not be restricted to global measures of switch costs, however. Stimuli that have varying numbers of inconsistent memory traces associated with them within a task-switching block provide a test of how such conflict affects local switch costs while addressing another possible explanation for global switch costs. Older adults have been shown to adopt a more cautious strategy when having to perform multiple tasks (Glass, et al., 2000). This explanation could be relevant in task-switching studies as well with older adults being more careful to respond correctly in the more demanding task-switching condition. If this overall strategic change were related to differential age

effects in global switch costs, then varying the stimulus competition within the task-switching block sidesteps this issue. The current study is designed to encapsulate the differences in stimulus conflict through competitor priming typically seen between blocks (task-switching blocks having more conflict than single task blocks) but has an additional benefit of varying this conflict within a task-switching block alone therefore avoiding any changes in subject's strategy across blocks.

The Current Study

The present study tested stimulus effects in a task-switching design. Waszak et al. (2003) showed that on switch trials a stimulus that previously appeared in the now irrelevant task is processed more slowly than those without this past interference. While the memory traces that cause this conflicting information are created automatically, to choose which of them is associated with the correct answer may be a top down control process. Therefore, an increase in switch cost for stimuli that have appeared in multiple tasks compared to those with no such stimulus history is a measure of the control needed to select from competing memory traces in task-switching.

In order to focus on the biasing effect of stimulus repetition in residual switch costs, this study used a long CSI of 1 *s*. This set up a strict test, as residual switch costs are already small effects. However, it provides information about the part of switch costs that is dependent on stimulus presentation. Stimulus repetition was manipulated in this study such that some trials in each task-switching block had stimuli that have been encountered before and some trials with novel stimuli. A stimulus priming theory to explain effects in task switching, such as from Waszak et al. (2003), suggests that stimuli that were previously processed in only the current task or no task at all should have faster

RTs than those with previous history in what is now an irrelevant task. Based on measures of age differences in executive control and global switch costs, older adults were expected to show even greater slowing with these stimuli due to the retrieval of irrelevant memory traces. That is, older adults should show greater local switch costs than younger adults under conditions of stimulus repetition that had stimuli that were previously presented in a now irrelevant task compared to stimuli with no competing memory traces.

CHAPTER 2

METHOD

Participants

Participants were 24 young (*M* age = 20 years) and 24 older adults (*M* age = 72 years). Young adults were from the participant pool at the Georgia Institute of Technology and received extra credit in a psychology course for their participation. Older adults were recruited from the local Atlanta community and received $10 per hour compensation for their time. Each session lasted between 1.5 and 2 hours.

Stimuli

Stimuli were 480 words that were either living or nonliving objects and either larger or smaller than a standard basketball. Half of the words fit into each side of each categorization ($^1/_4$ words are living and larger than a basketball, ¼ are living and smaller than a basketball, ¼ are nonliving and larger than a basketball, ¼ are nonliving and smaller than a basketball).

The task cue was a single letter that appeared above the word stimulus. The cue, either "L" to designate the Life (living/nonliving) task or "S" to designate the Size task, appeared 1000 ms before the word stimulus and remained on the screen during the trial.

Design

Trials were presented in single task and task-switching blocks. Each session began with single task blocks. The purpose of the single task blocks was to present stimuli initially in order to test the effect of repetition priming in the task-switching block that immediately followed. Each single task block was, by definition, only one task.

Therefore, two short single task blocks were presented before each task switching block. Each word was presented once in the critical task-switching block. Half of the stimuli appeared in the single task block and were repeated twice. While repetition priming typically continues to speed processing with each repetition (Logan, 1990), even one presentation is expected to produce an effect from repetition. Multiple repetitions in the same task are not expected to further influence performance (Waszak et al., 2003, 2005). Repeating some stimuli leads to 2 levels of stimulus repetition: zero and two repetitions. Each of the single task blocks had 24 trials and the task-switching blocks had 48 trials. This pattern of two single task blocks followed by a task switching block was repeated ten times (with different stimuli), for 960 trials in total (see Table 1).

Table 1.Total Number of Trials in Each Trial Condition (per participant) for Task-Switching Blocks

# Reps	**Switch**	**Living**	**Size**	**Repetition Condition**		
				Same	**Different**	**Mixed**
Zero	Switch	Living	Big	30		
			Small	30		
		Nonliving	Big	30		
			Small	30		
	Nonswitch	Living	Big	30		
			Small	30		
		Nonliving	Big	30		
			Small	30		
Two	Switch	Living	Big	10	10	10
			Small	10	10	10
		Nonliving	Big	10	10	10
			Small	10	10	10
	Nonswitch	Living	Big	10	10	10
			Small	10	10	10
		Nonliving	Big	10	10	10
			Small	10	10	10

The required task for initial presentations of each word (in the single task trials) varied. For one-third of the stimuli, both repetitions were of the same task as that later required in the task-switching block. For another one-third of the stimuli, the repetitions required a different task than that of the task-switching block. For the final third, one of the repetitions was in the same task and the other repetition in the other task from that required in the later task-switching block.

Half of the trials in the task-switching blocks were switch trials and half were nonswitches. Combined with the single task blocks, there are three types of trials based on switch and context: switch trials (task-switching context), nonswitch trials (task-switching context) and single-task trials.

Participants made a keypress response (using the ‘z’ or ‘/’ keys of a computer keyboard) for each trial based on their categorization of the word. Participants responded using those two keys regardless of the task they were performing.

CHAPTER 3

RESULTS

I replaced participants who had unexpected/incorrect answers on 13% or more of the trials. Six older adults and 5 younger adults were replaced according to this criterion. Mean error rates were 5.0% (*SD* = 2.1%) for older adults and 6.0% (*SD* = 2.7%) for younger adults. Responses < 250 *ms* were eliminated for both groups and those > 4000 *ms* for older adults and > 3000 *ms* for younger adults were also dropped. These criteria eliminated 3.2% of the older adults' responses and 3.3% of the YA responses. Mean RTs were calculated from the remaining trials.

Note that the design required that single task blocks always came before task-switching blocks, because they presented the initial repetitions of the stimuli for the task-switching trials. Therefore, a typical global switch cost, which measures the differences due to single task or switching contexts, could not be calculated. This typical calculation of cost would not distinguish between those context differences (single vs. task switching) and mere experience with the stimuli in each task. However, my measures of local switch costs across repetition conditions are designed to capture and account for the stimulus-response conflict that may be present in typical measures of both local switch costs and global switch costs. Even without a measure of global switch costs here, the local switch costs across conditions relate to the global switch cost as well.

Comparisons between the various types of stimulus repetition in this study are designed to determine the role that stimulus repetition plays in task-switching costs. These comparisons are made across switch and nonswitch trials in the critical task-switching blocks. There are four stimulus repetition conditions: zero repetitions [ZERO],

two repetitions in the same task [SAME], two repetitions in a different task [DIFFERENT], and two repetitions mixed with one being in the same and the other in the different task [MIXED].

Errors were highest in the DIFFERENT condition (7.6%), followed by MIXED (6.4%), ZERO (6.0%) and SAME (4.5%), a significant difference, $F(3, 138) = 10.35$, $p < 01$, in the same direction as the RT results, thus there is no evidence for a speed-accuracy tradeoff to account for the current results. The two age groups did not differ in number of errors, $F(1, 46) = 1.20$, $p > .27$ (young = 6.6%, old = 5.6%).[1]

Waszak et al. (2003) found that stimuli with previous history in a currently irrelevant task had larger switch costs than stimuli without this past experience. I wanted to test that finding in the current study. Recall that another motivation for the current study was that in prior studies, local switch cost measures often do not show an age differences while global switch costs do. To address the specific role of prior stimulus experience, I examined age differences in performance in three separate analyses. Shown in Figures 1 and 2 are Mean RTs as a function of repetition and switch for younger and older adults, respectively.

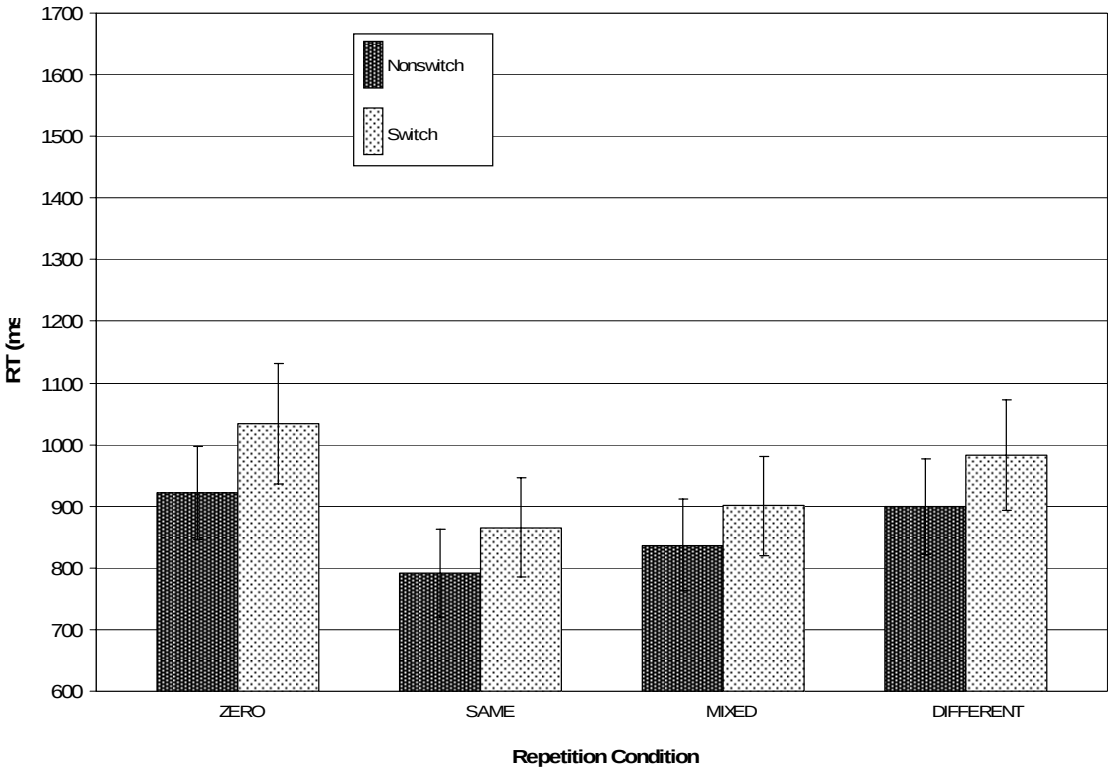

Figure 1. Mean reaction time by repetition and switch conditions for younger adults. Error bars are 95% confidence intervals.

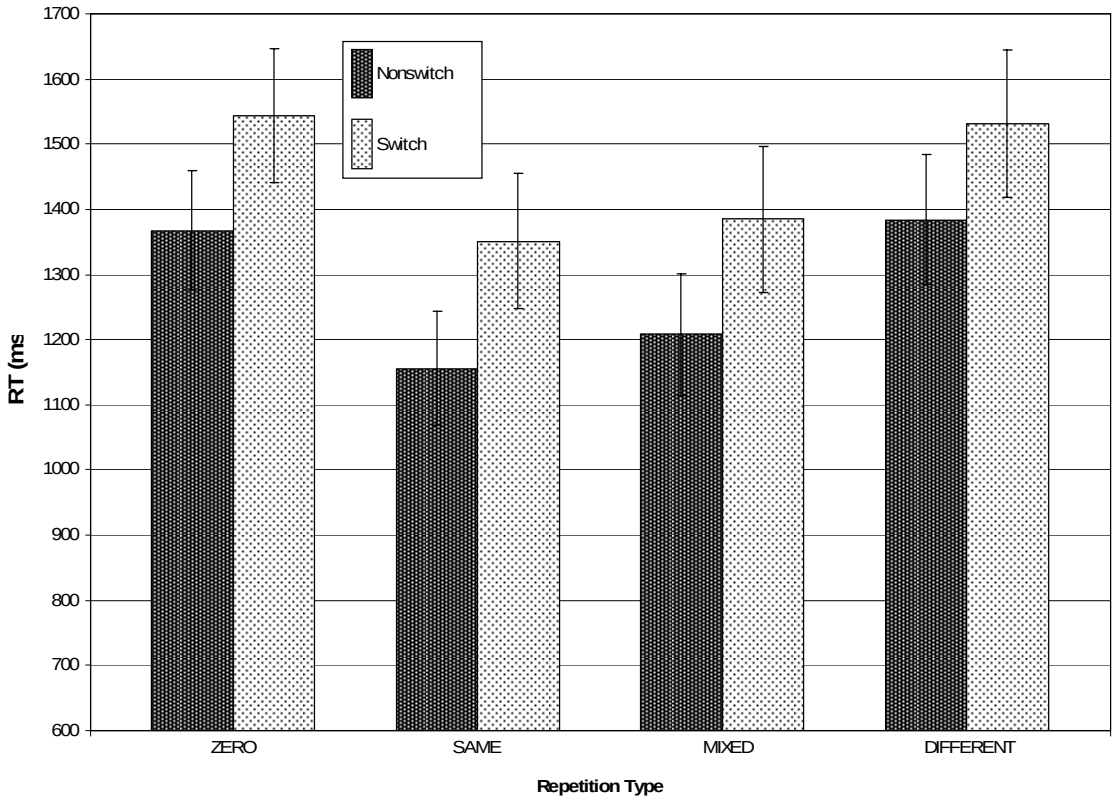

Figure 2. Mean reaction time by repetition and switch conditions for older adults. Error bars are 95% confidence intervals.

First, the data were analyzed in an analysis of variance (ANOVA) with repetition, task and switch type as three within-subject factors and age as the between-subject factor. This led to a 4 (repetition type) x 2 (task) x 2 (switch type) x 2 (age) mixed factor ANOVA. There were significant main effects for repetition condition, F (3, 138) = 79.92, MSE = 17933, $p < .01$. Overall, the ZERO repetition was slowest (1219 *ms*), followed by DIFFERENT (1201 *ms*), MIXED (1084 *ms*), and SAME (1044 *ms*). The two tasks differed in overall speed, 1062 *ms* and 1213 *ms* for LIFE and SIZE respectively, F (1, 46) = 115.12, MSE = 37936, $p < .01$. As expected, switch trials were slower than nonswitch trials, 1202 *ms* and 1073 *ms* respectively, F (1, 46) = 68.56, MSE = 46653, $p < .01$.

Turning next to the influence of age, older adults were slower than younger adults, F (1, 46) = 26.30, MSE = 1567519, $p < .01$. Repetition type influenced the performance of older more than younger adults, F (3, 138) = 5.10, MSE = 17933, $p < .01$. While older adults were slower than younger adults overall, this age difference was particularly large in the Size judgment, Task x Age interaction, F (1, 46) = 38.08, MSE = 37936, $p < .01$. Older adults also showed a greater local switch cost, Switch type x Age interaction, F (1, 46) = 8.36, MSE = 46653, $p < .01$.[2]

Repetition type interacted with Task, F (3, 138) = 5.65, MSE = 12881, $p < .05$, such that for the SIZE task, MIXED and SAME were similar (MIXED was only 29 ms slower than SAME) but DIFFERENT was much slower (DIFFERENT was 134 ms slower than MIXED) while for the LIFE task, the conditions were more evenly separated (MIXED 53 ms slower than SAME, DIFFERENT 99 ms slower than MIXED). Repetition type did not interact with Switch type, F (3, 138) < .86, $p > .46$. Task did interact with Switch type, F (1, 46) = 6.35, MSE = 20402, $p < .05$. Overall the LIFE task

had 159 *ms* local switch cost overall and the SIZE task had 88 *ms*. Further, the three way interaction among repetition type, task, and switch was also significant, F (3, 138) = 2.78, MSE = 15976, $p < .05$. Local switch costs varied across Repetition type more for the SIZE task (from 139 to 171 *ms*) than for the LIFE task (from 59 to 134 *ms*). This may be related to the overall slower response times to the SIZE task. The Repetition type x Switch type x Age interaction was not significant, $F < .84$, $p > .47$.

The full ANOVA did not reveal differences in switch costs across repetition type as had been expected based on Waszak et al. (2003). Note however that the full ANOVA included more repetition types than the Waszak et al. study. Therefore I next ask more specifically whether prior experience in an irrelevant task influences switching performance. To do this, the ZERO condition was compared to the DIFFERENT condition. It is important to emphasize that this comparison simply adds exposure to an irrelevant task to the measure of switch cost. This 2 (repetition type) x 2 (switch type) x 2 (age) mixed factor ANOVA revealed a local switch cost, the main effect of switch condition, F (1,46) = 50.06, MSE = 16236, $p < .01$, and also a marginal interaction between age and switch type, F (1, 46) = 3.05, MSE = 16236, $p = .09$. Local switch cost was larger for older adults (local switch cost: 162 ms) than for younger adults (98 ms). The repetition type, ZERO vs. DIFFERENT, was not different, nor did this factor interact with age group or switch type, all other Fs < 2.38, ps > .12. This appears to suggest that repetition of a stimulus in another task does not influence overall performance in the present task nor switching performance. This is inconsistent with the results of Waszak et al.

Note that measures of global and local switch costs reflect the relative position of three condition means: single task, and nonswitch and switch conditions of a mixed block. One reason for age differences in global but not local switch costs may be that nonswitch trials involve significantly more control requirements in older adults compared to younger adults (see also Spieler, Mayr, & LaGrone, in press). Therefore, I next focus on the possible influence of prior history on nonswitch performance. If the pattern of age differences in the literature is due to how stimulus history affects the nonswitch trials in a task switching condition, nonswitch trials should show an age interaction with repetition type. In a 3 (repetition type) x 2 (age) ANOVA of only the nonswitch trials, Age x Repetition type was significant, F (1, 46) = 8.53, MSE = 11703, $p < .01$. For older adults, DIFFERENT (1385 ms) was much slower than MIXED (1210 ms) which was less different from SAME (1160 ms). For younger adults, the difference in RT across conditions was not as great: DIFFERENT (903 ms), followed by MIXED (837 ms) and SAME (792 ms). Certainly these results suggest that prior stimulus experience may influence the relative position of switch and nonswitch conditions for young and old. However, the lack of a significant interaction between age, switch type and repetition in our overall ANOVA also makes it difficult to conclude this definitively.

Stimuli in the MIXED condition have previous history with both the relevant task in the switching block and the irrelevant task. For half of these trials, the first presentation of the stimulus was for the relevant task, for the other half the irrelevant task presentation was first. Activation of memory traces should not depend on this order of presentation, but finding an effect here would lead to information about whether preference was given to the original memory trace associated with a stimulus or the most

recent one. No differences were found for stimuli in the MIXED condition based on whether the relevant task for the switching block trial was presented in the first or second single task block ($F < 1$).

CHAPTER 4

DISCUSSION

This study was motivated by findings in the literature that previous associations among specific stimuli, tasks and responses for currently irrelevant tasks in a task switching context increase local switch costs (Waszak, et al., 2003, 2005). Further, the study tested whether the typical age interaction in global switch cost but not local switch cost measures (Kray & Lindenberger, 2000) is related to previous task associations. My results suggest some support for this second hypothesis in specific comparisons of nonswitch trials across Age, however, the overall interaction of Age x Repetition type x Switch was not significant. Overall, the current study does not support the idea that previous task associations of specific stimuli contribute to local switch costs.

Findings from the Current Study

In this study, I find that the type of stimulus repetition affects performance for individual stimuli. Certainly, prior exposure to the stimulus in the currently relevant task results in facilitation relative to prior exposure in the irrelevant task. The central question of this study concerns the impact of different types of repetition priming on switch costs. Overall, local switch costs are not significantly different across repetition types. Thus, previous history of the stimulus, in the conditions of this study, does affect overall RT but does not account for residual local switch costs.

Older adults demonstrate larger switch costs than younger adults. Older adults also show more influence from repetition history than younger adults. The question of how irrelevant task stimulus history differentially affects switch costs for the two age groups is examined in more specific comparisons. In a comparison of only stimuli with

irrelevant task history and new stimuli, there is still no difference in local switch cost depending on stimulus history. These two repetition conditions did not differ in overall RT for either younger or older adults. Thus, these results suggest that irrelevant task history does not modulate switch costs.

The present results show an age by local switch cost interaction. Older adults have greater local switch costs than younger adults. Note that we can measure two types of switch costs, global and local switch costs. Although global switch are not measured in this study, the measures of local switch cost were designed to capture possible stimulus repetition effects in global switch costs. Global and local switch costs involve three points of measurement: single task blocks, nonswitch and switch trials from the task switching blocks. Both types of switch cost measures include nonswitch trials from the task switching blocks. For local switch costs, nonswitch trials differ from switch trials in the task immediately preceding them, but switch and nonswitch trials have the common context of the task switching block. Stimuli in task switching blocks typically appear multiple times in each task. For global switch costs, nonswitch trials differ from single task trials in the context in which they appear. Single task blocks also do not build irrelevant stimulus histories for trials later in that block while task switching blocks do. Nonswitch trials in the current study differ in stimulus histories depending on repetition condition, and these trials with irrelevant stimulus history were differentially slower for older adults. While repetition does influence performance on these nonswitch trials, there was no evidence that this repetition history modulated switch costs.

Although age effects in these comparisons are informative, I did not replicate certain expected findings based on previous studies. In contrast to the current experiment,

Waszak et al. (2003) found that switch trials were slower for stimuli with history in an irrelevant task compared to no irrelevant task history. I found no interaction between switch cost and repetition type. However, there are several important differences between the present study and the Waszak et al. study that may contribute to these different results. I next consider these alternatives, followed by a discussion of what these results mean for the stimulus priming account of residual switch costs.

Comparisons to Waszak, Hommel, & Allport (2003)

Stimuli in the present experiment were selected so they would not be repeated in multiple task-switching blocks. This required many unique stimuli and word stimuli worked well for this purpose; however, they are quite different from Picture-Word Stroop style stimuli used in Waszak et al. (2003, 2005). The Stroop aspect of the stimuli used by Waszak et al. and others (e.g. Allport, Styles & Hsieh, 1994; Allport & Wylie, 2000) means their stimuli had naturally dominant and nondominant tasks. In Waszak et al. (2003), stimuli were initially presented in the word reading (dominant) task. Following this, they were presented as switch and nonswitch trials of either picture-naming (inconsistent task history) or word reading (consistent task history) task conditions. Waszak et al. focused on the dominant word reading task (picture and word pairs were kept intact) and found that switch trials were slowed by irrelevant task history of a stimulus while nonswitch trials were unaffected. The same pattern was not found for their nondominant task, but their experiment did not explicitly test for history of the nondominant task.

The current experiment does not have an obviously dominant task and so the effects were not expected to differ across task, although this was not entirely the case.

Responses to the Size task were about 200 ms slower than the Life task and local switch costs were smaller in Size versus Life. The Size judgment task was more subjective than the LIFE task, not only making it more difficult in the later analyses to determine which responses were accurate, but also the slower, more difficult judgment may lead participants to focus more or less on the stimulus during the trial.

Possibly, only stimuli that lead to a dominant response show effects of repetition in local switch cost measures. Stimulus repetition associates activation of a task with a stimulus. Performing the nondominant task requires extra activation of that task, which does not dissipate by the time of an immediately following switch trial to the dominant task, and creates competition for the switch trial. Thus, on these switch trials (to the dominant task), task competition is high. Task competition is high for both switch and nonswitch trials of the nondominant task, which leads to no change in switch cost (the difference between switch and nonswitch trials) for the nondominant task (Waszak, Hommel, & Allport, 2005). The current experiment had no clearly dominant task and did not replicate the increase in local switch costs with more stimulus repetition found in Waszak et al.

The theoretical claims of stimulus repetition in task switching do not require using only a particular stimulus set and so the current study may help place boundaries on the type of stimuli that can be used. Koch and Allport (2006) have shown that stimulus repetition affects switch costs with non-Stroop style stimuli when using a very small stimulus set (digits 1-9). In that task switching study, each of the single digit numbers was presented in the same task, an even/odd judgment or a magnitude (greater or less than 5) judgment, for the first four blocks (96 trials each). In the final block of the study,

the task that had been associated with each digit was changed. For example, if "3" had required the even/odd judgment for the first part of the study, in the last section, "3" would require the magnitude judgment task. For a small group of individual number stimuli, they found larger switch costs for changing the task that was associated with a particular stimulus, extending the work of Allport, Styles, and Hsieh (1994) that classes of stimuli are influenced by previous task history. With individual repetitions of non-Stroop stimuli, the current study extends Waszak et al.'s claim that stimulus history is carried at the individual stimulus level.

A final important difference between the current study and Waszak et al. (2003, 2005) concerns the reuse of stimuli. Waszak et al. reused stimuli in four times over the testing session in order to increase the number of trials in the study. Thus, "unprimed" stimuli were compared to those with irrelevant task histories, but those stimuli were not truly unprimed but rather increasingly positively primed by consistent task history over the four cycles of presentation. In the current study, relevant task history seemed to be more of a benefit than irrelevant history was an interference.

Although not specifically a difference from Waszak et al. (2003), the long CSI used in this study may suggest another boundary condition for the memory trace account. The cue was presented 1 *s* before the stimulus, allowing it to be fully processed and to bias encoding of the upcoming stimulus. Cues can themselves be considered a part of the stimuli (Logan & Bundesen, 2003) and a long CSI may allow the stimulus associated with the Life cue and with the Size cue to be processed as distinct memory traces. The long availability of the task cue may in fact serve as an effective retrieval cue and help to lessen the influence of prior stimulus history. Stimulus history may have the most impact

on switch costs with short CSIs, particularly when task competition is high due to previous experiences in the now irrelevant task (Koch & Allport, 2006). I focused on residual cost to help establish the role of memory traces in task switching costs that remain after ample time for task preparation. While the role of bottom up stimulus encoding processes may influence all switch costs, not just the residual cost that is most apparently dependent on the stimulus, the influence of stimulus repetition here sets a foundation for future exploration of how stimulus repetition affects performance in task switching experiments.

Conclusions from the Experiment

The present study helps to move task switching beyond extremely simple perceptual discriminations and extremely small numbers of stimuli common in many prior studies. The experiment demonstrates that age differences in local switch costs are present under some conditions. Moreover, the results suggest several possible avenues for the exploration of prior stimulus history on task switching performance. The variations in the current experiment from previous research were intended as a straight-forward test of how prior stimulus history influences task switching. While I found some support for an age effect of stimulus history in task switching, the differences in my findings from those in the literature could be due to the many differences in design. The current study was a stringent test of the influence of prior stimulus history. Evidence that stimulus history affects switch costs in task switching studies has been found with other experimental conditions and stimuli (e.g. Koch & Allport, 2006), however, these results are not replicated in the current study, highlighting the limits of stimulus history as an explanation of local switch cost. Allport and Wylie (2000) proposed that residual switch

costs are not a measure of the time needed to reconfigure task sets, or at least that switch costs do not entirely represent time for this process, due to the irrelevant task history carried by stimuli. In their studies, irrelevant task history led to performance costs most evident on switch trials, thus those trials with history in the irrelevant task had larger switch costs than those with only relevant or no task history. Waszak et al. extended this idea to test item-specific priming history for a set of stimuli.

Allport, Styles and Hsieh (1994) explained switch cost as due to proactive interference on switch trials due to interference from a previous task that diminishes over time (task set inertia). Later extensions of this idea added that priming tasks for specific stimuli would affect this lingering interference. In the current study, stimulus specific interference did not affect switch costs, suggesting that the interference of task set inertia (that leads to switch costs) does not always reflect irrelevant task history as well. This result does not deny proactive interference as an explanation for local switch costs and the current findings support that long term priming has influence (seen in the main effect of Repetition type), but long term, stimulus specific priming is not supported as an explanation for residual switch costs in this design.

Future Directions

Although previous literature (Allport & Wylie, 2000; Waszak, Hommel & Allport, 2003, 2005) that motivated the current study focused on residual switch costs and so had long CSIs, recent work offers the suggestion that length of preparation before the stimulus appears may influence the effect of previous history. Stimulus history has the most influence with short CSIs (Koch & Allport, 2006), when the task is perhaps most ambiguous or competition for task selection is highest. Long CSIs allow time for any task preparation processes to take place before the time measured for the response. It is the residual switch costs that remain with long CSIs that have helped spark debate over

what control processes are needed for task switching, yet stimulus priming may not have the greatest impact on this component of switch costs.

Footnotes

1. Error proportions were subjected to an arcsin transformation [arcsin(√proportion)] before the ANOVA.

2. Much of the literature reports no age interaction in local switch cost, however, some of these studies also report using scores that have been transformed in some way for each participant. Transformed RTs scores are used to reduce the impact of individual differences in RT, specifically in aging studies this done to account for general slowing. Older adults do have slower responses overall but this study is interested in differential RT effects across conditions that could be masked by reducing the differences across the conditions. In the current study, I report results of the ANOVA using untransformed means. In a separate analysis to account for overall speed differences among participants, I divided the mean RT of each condition for each participant by that participants' overall mean. This analysis showed no age by local switch interaction, F (1, 46) = 2.57, MSE = .033, p = .12, which is consistent with previous literature. In the ANOVA using these proportions, older and younger adults did not differ in overall speed, F (1, 46) < 1, MSE = .038, p > .32. Repetition type still influenced the performance of older more than younger adults, F (3, 138) = 8.21, MSE = .014, p < .01, but the Task x Age interaction was no longer significant, F (1, 46) = 3.01, MSE .020, p = .09.

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